

Monitoring of Arctic Conditions from a Virtual Constellation of Synthetic Aperture Radar Satellites

Hans C. Graber

RSMAS - Division of Applied Marine Physics

Center for Southeastern Tropical Advanced Remote Sensing

University of Miami

4600 Rickenbacker Causeway

Miami, FL 33149, USA

phone: (305) 421-4952 fax: (305) 252-4407 email: hgraber@rsmas.miami.edu

Peter J. Minnett

RSMAS - Division of Meteorology and Physical Oceanography

University of Miami

4600 Rickenbacker Causeway

Miami, FL 33149, USA

phone: (305) 421-4104 fax: (305) 421-4696 email: pminnett@rsmas.miami.edu

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LONG-TERM GOALS

Utilize a constellation of satellite radars to monitor the melting and freezing cycles of the Arctic Ocean north of 65°. From difference maps of a timeseries of images deduce changes in ice extent, ice-type, and lead expansion/contraction with temporal resolutions from hours to days. Ultimately provide a routine Arctic coverage and generate products for operational purposes, and as validation, boundary conditions, and initialization to numerical ice-ocean forecast models.

OBJECTIVES

- a) To create daily Arctic SAR images from the CSTARS SAR constellation.
- b) To test and develop an appropriate ice-type classification technique from SAR attributes (e.g., backscatter) that distinguishes between new-, first-, and multi-year ice, and water, with focus on detection of the ice edge and leads.
- c) To generate daily Arctic ice-type maps from the CSTARS SAR constellation using the ice-type classification technique mentioned in 2.
- d) Comparison of ice-type products from multi-frequency, multi-polarization SAR sensors to gauge whether SARs can be combined, and if so, generate daily Arctic ice and ice-type maps with improved spatial coverage.
- e) Generation of difference images with temporal resolutions of hours to days between Arctic coverage and ice-type mosaics to illustrate changes in ice extent, ice edge, leads, and ice-types.

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- f) From amplitude and coherent change detection (ACD and CCD) images estimate global spatial rate of melting during the summer months and freezing during the winter months.
- g) Monitoring of icebergs and breakage of glaciers and the speed of motion.
- h) Monitoring of the Northwest Passage.

APPROACH

2013 MIZ Pilot Program: Starting in June to end of September 2013, CSTARS provided satellite data collections for three different efforts during the Marginal Ice Zone (MIZ):

- 1) Large-Scale Evolution of MIZ
- 2) Buoy Cluster Tracking
- 3) SIZRS Flight Tracks

The objective of the satellite collections during the pilot program year is to understand how effective synthetic aperture radar is to support these various experimental activities. The data will also be used to determine how to improve collection timelines and deliveries for the full scale experimental year, the type of sensors and imaging modes needed and how frequently collects should occur.

Large Scale Evolution of the MIZ

Large-scale images were used to monitor the Central Beaufort Gyre along 150 W and following the ice retreat in a northward direction. These images will be used as overviews of ice edge position, marginal ice zone width, and sea ice deformation. Sequences of images will help to identify where ice break-up commences and how the MIZ evolves during the warmer melting season. In addition, several high-temporal resolution satellite images will allow examination of ice motion and ice deformation at hourly scales.

For this project we collected primarily RadarSat-2 ScanSAR images with large swath widths of 300 km to 500 km and a spatial resolution of 100 m. Polarizations included both HH and HV for better discrimination of ice versus water.

Buoy Cluster Tracking

The primary goals of the buoy arrays drifting inside the ice are to examine the ice and ocean dynamics leading up to the transition into the MIZ, break-up of ice floes (i.e., floe-size distribution (FSD)), and the dynamic-thermodynamic coupling of the ice decay. Satellite remote sensing is especially useful here in observing the change in the ice FSD before, during and after dynamic events such as storms or rapid break-up of large ice sheets. The connection between ice deformation and the decay of the ice cover, which is linked through open water production (and hence solar energy absorption). For this, it is important to observe open water fraction and its connection with high-frequency dynamics. This requires sub-daily repeat imagery. The open water production rates can be used with observed and calculated atmospheric fluxes, upper ocean warming and basal melt rate from the buoy data to understand the dynamic-thermodynamic coupling. Critical is how the high-frequency dynamics determined from the buoy array is related to the lower-frequency open water production. This needs to be tested with high resolution SAR collection within key events. Highest resolution images (1 to 2 m)

are required to monitor the evolution of cracks and leads as they develop and refreeze in the winter and, then, melt out during the summer.

Several time periods were examined during this past summer in terms of (1) when the ice is reasonably solid, (2) beginning of break-up and melt, and (3) evolution into an MIZ and melt, with small floe sizes.

StripMap resolution satellite SAR were used to track the 2012L buoy site which is configured with an Ice Tethered Profiler (ITP), Autonomous Ocean Flux Buoy (AOFB), and CRREL Ice Mass Balance (IMB) buoy so comparisons of the in-situ data can be calculated with the SAR data. By tracking the existing buoy cluster these imagery will provide guidance for, and a determination of, imagery needs for the 2014 field season.

For this project we collected primarily TerraSAR-X StripMap and SpotLight images with swath widths of 40 km and 10 km and spatial resolutions of 3 m and 1 m, respectively. Polarizations included both HH and HV for better discrimination of ice versus water. These higher resolution images will delineate better open water leads and cracks in the ice as well as melting ponds on ice floes.

Seasonal Ice Zone Reconnaissance Surveys (SIZRS)

The purpose of the Seasonal Ice Zone Reconnaissance Surveys (SIZRS) program is to acquire repeated ocean, ice, and atmospheric measurements across the Beaufort-Chukchi Seas seasonal sea ice zone (SIZ) utilizing US Coast Guard Arctic Domain Awareness (ADA) flights of opportunity. The SIZ is the region between maximum winter and minimum summer sea ice extents. SIZRS flights will be used to monitor the full range of positions of the MIZ where sea ice interacts with open water. The increasing size and changing air-ice-ocean properties of the SIZ are central to recent reductions in Arctic sea ice extent. Satellite images will follow the flight line of the ice-covered portion along 150 W with image centers in 1 degree intervals from 72 N to 82 N.

For this project we collected primarily RadarSat-2 ScanSAR images with large swath widths of 300 km to 500 km and a spatial resolution of 100 m. Polarizations included both HH and HV for better discrimination of ice versus water.

Storm Tracking in the MIZ

The purpose of polar lows and storms as they move from open water to ice-covered region of the MIZ is to understand better the impact of open ocean waves and swell in initiating ice breaking-up and modifying ice distributions.

For this project we collected primarily RadarSat-2 and Cosmo-SkyMed ScanSAR images with large swath widths of 200 km to 500 km and a spatial resolution of 100 m. This coverage will provide overview of the storm impact on the MIZ.

WORK COMPLETED

Planning and programming the satellite collections for the dynamic and sometimes erratic movements of the buoy was not trivial and required tasking the satellite as little as 12 hours before imaging. About 50% of the tasked images were successful to include the buoy. This image dataset will allow for a detailed analysis of the ice conditions such as ice distribution, open water leads and ice types in the vicinity of the buoy cluster 2012L. Figure 1 shows an example when three closely coordinated

TerraSAR-x images were successful to capture the buoy's position. A second opportunity was achieved a few days later on 17 July 2013 capturing the buoy again.

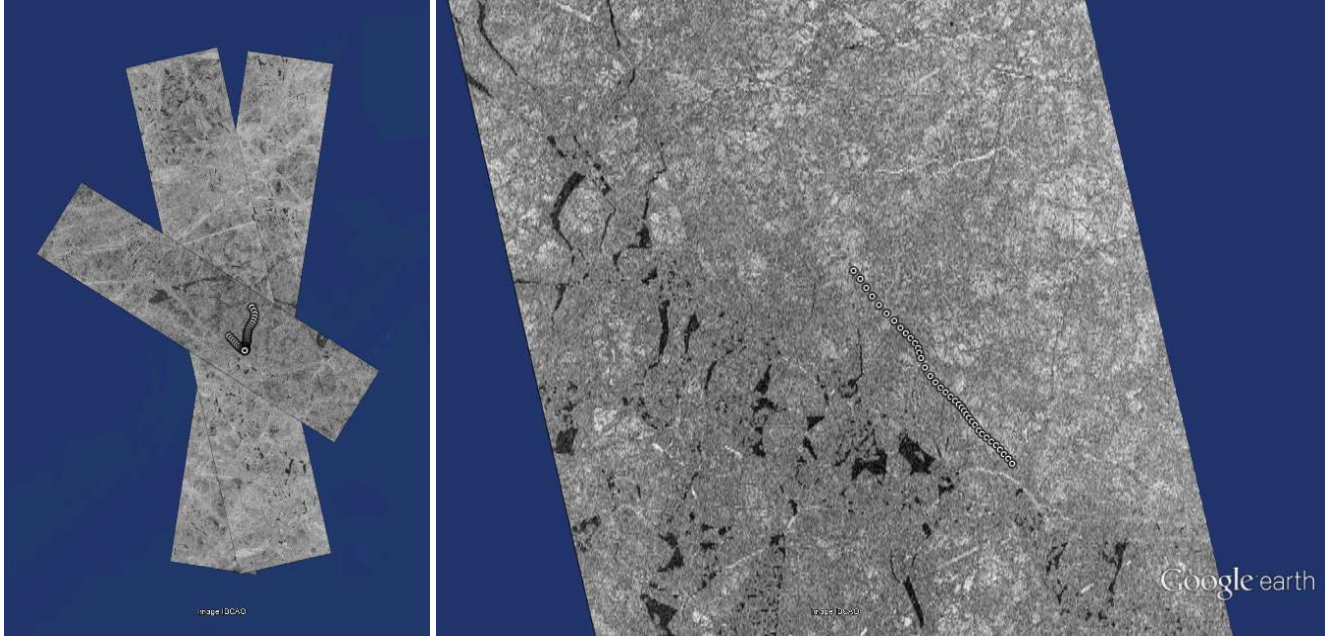


Figure 1: Left: Three TerraSAR-X StripMap images spanning June 30 to July 1, 2013 capturing the buoy's path. Right: Zoomed TerraSAR-X image from 17 July 2013 @ 01:28 UTC shows the buoy's track parallel to ice floes with open water leads.

During the 2013 summer melt of the MIZ we collected more than 125 satellite images from different sensors and in different modes as listed in Table 1.

Table 1: List of projects, satellite sensor and imaging imode, the spatial resolution and the number of collects for the Pilot Projects 2013 experimental phase. (The additional collects in parentheses could also be acquired).

Project	Sensor & Mode	Resolution	# of Collects
Buoy 2012L	TerraSAR-X -- StripMap	3 m	36 (42)
	RadarSat-2 -- WideFine	5 m	1
Buoy 2013F	TerraSAR-X -- SpotLight	1 m	21 (5)
Large Scale Area	RadarSat-2 -- ScanSAR	100 m	18
Storm Tracking	TerraSAR-X -- ScanSAR	16 m	1
	TerraSAR-X -- OceanMode	33 m	1
	Cosmo-SkyMed -- ScanSAR	50 m	1
TOTAL COLLECTION			79 (47)

Figure 2 shows an example of using multi-sensor, high-temporal coincident images to estimate ice motion and deformation. Here we use a combination of SAR and EO images starting with a Cosmo-SkyMed SAR image collected on 01 September 2013 @ 12:48:50 UTC and then a Landsat-8 optical image acquired on 01 September 2013 @ 22:32:13 UTC about 10 hours 16 minutes and 37 seconds later which was followed by a TerraSAR-X SAR image on 02 September 2013 @ 03:45:07 UTC about 5 hours 13 minutes 6 seconds later. In the figure several ice floes are outlined in each image and in the Landsat-8 image we show the relative positions of these ice floes and the velocity vectors. In general the ice floes move southwest except near the bottom the ice floe there displays a remarkable rotational characteristic.

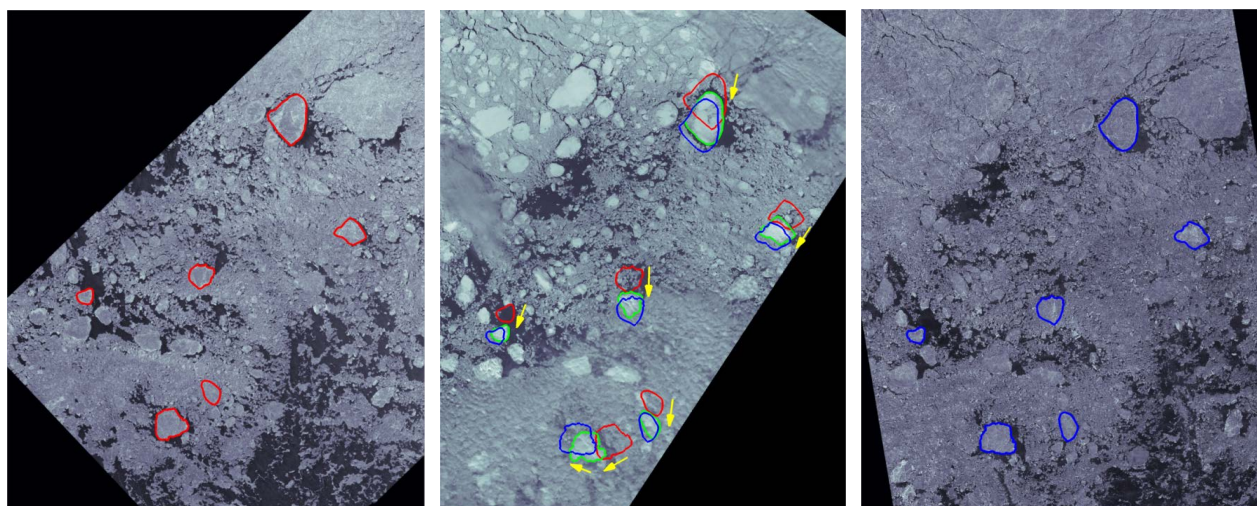


Figure 2: *Left: Cosmo-SkyMed image on 01 September 2013 @ 12:48:50 UTC. Selected ice floes are outlined in red. Center: Landsat-8 image on 01 September 2013 @ 22:32:13 UTC. The positions of the previously selected ice floes are outlined in green. Superimposed are also the positions of the ice floes 10 hrs and 16 min earlier and 5 hrs 13 min later. The arrows indicate the speed of translation as well as rotation (lower bottom cluster). Right: TerraSAR-X SAR image on 02 September 2013 @ 03:45:07 UTC. Previously selected ice floes are outlined in blue.*

Typical speeds of the ice floes between the Cosmo-SkyMed and LandSat-8 images are 10 km/day to 15 km/day and a general direction of south to southwest. The ice floes slowed down between the LandSat-8 and TerraSAR-X images to about 5 km/day to 10 km/day but turning more southwesterly. This is most obvious with the lower bottom floe that is rotating to northwest.

RESULTS

We have successfully implemented and executed a significant satellite SAR collection program during the 2013 MIZ Pilot Program supporting different projects in different regions with the Beaufort Sea and Arctic region.

IMPACT/APPLICATIONS

The potential impact of these satellite collections and analysis studies by this project will lead to an improved algorithm of ice edge detection and ice type classification. Also the project will demonstrate that obtaining a daily satellite imagery of the MIZ covering the entire Arctic region is feasible with the

constellation SAR satellites available to CSTARS. Furthermore, the data will lead to considerable improvement of the Navy's ice prediction model.

RELATED PROJECTS

Radar Remote Sensing of Ice and Sea State and Air-Sea Interaction in the Marginal Ice Zone
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